Comparative Study of Availability on Energy/Environment Commissioning Using Existing HVAC Simulation Programs for a Model Building

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Summery.

Results of comparative study for five typical simulation programs (HASP/ACSS, EnergyPlus, DOE-2, Dest and HVACSIM$^+$(J) are discussed using. a certain reference model of an actual building. The maximum and annual cooling and heating loads and annual energy consumption are compared. Efforts were made to make calculation conditions coincide with each other, but it was not always completely successful due to specific character of algorithms included in each program, so that calculation results differed a little with each other and with actual results. Several case studies have been carried out for each program how design parameters and/or control strategies result on energy consumption and/or indoor environment, which proved availability of each program for commissioning use in various phases depending on their characteristics.

Introduction

Public and semi-public simulation tools in each country are available relatively easily now. Though each tool has high degree of completion, it is disappointing that each tool is not used so often in actual design processes and verification processes.

Various reasons are considered. It seems that users cannot decide to apply each tool because the features, precision and restrictions in functions of each tool are not made so clear. In many cases, the term "precision" does not indicate the absolute precision of calculation result, but indicates the reproducibility of system behaviors about whether or not phenomena are simulated correctly and whether or not dimensional relationship in a relative sense is reproduced correctly.

Latter half of the paper [1], submitted to Annex 40 meeting, included comparison study on various HVAC systems simulation programs. Among tools expected to well perform each style of commissioning business, system simulation program will be useful for design commissioning, post acceptance commissioning and on-going commissioning. Five typical programs are compared about their functions and energy calculation results in order to verify availability of system simulation programs as a commissioning tool. HASP/ACSS, EnergyPlus, DOE-2, Dest and HVACSIM+ were examined in comparison with actual operation results.

The content has been revised in this paper with the final effort by authors for the final report of a committee devoted to establish guideline to simulation tools for building commissioning, which has been admitted to transfer as an Annex 40 work to its final report to follow the previous paper [1].

1. Necessity of system simulation in commissioning

In commissioning of the HVAC system, it is required to express the system performance in a quantitative way. The term "performance" here indicates not only the "peak performance" meaning the system capacity, which is often used in the design, but also the annual and periodical performance with regard to the room environment and energy. For this purpose, the designer himself must understand and evaluate the system behaviors and system performance in each season including the off-peak period. System simulation for predicting the room air quality and energy performance is regarded as one of effective tools for such understanding and evaluation. And in the design phase, system simulation is required from the viewpoint of optimal design also. In commissioning during the operation phase, it is required to diagnose the operation as well as detect and analyze defect about whether or not the actual system is operating according to the design intention, what are causes if the actual system is not operating to meet with the design intent. It is natural that examination using a dynamic simulation tool is necessary when dynamic analysis is required.

2. Comparison of calculation results of reference system using existing programs

2.1 Selected programs

Five programs were selected for comparison. The HASP/ACSS was developed by SHASEJ in 1985 that has not formally been revised since then and cannot be said very often used and yet very famous in Japan. No graphical user interface has ever been sold out in the market except for a private version. The EnergyPlus the first version of which was issued in 2001 from LBNL, sponsored by DOE (Department of Energy), is an extended version of both DOE2 and IBLAST and equipped with far more flexible functions than these and with capability of dynamic simulation as well as interfacing to foreign programs such as CFD and AUTOCAD in the future. The DOE2 was developed by LBL under the sponsorship of DOE in early 1980s, and has been often revised and most popularly used in USA, especially in case of regulated by laws or guidelines on energy conservation and/or sustainable building design. Graphical user interfaces has been progressively developed, such as *Power DOE*. DeST was developed in Tsinghua University, China, since early 1990s and the first version was issued in 2000, which basically aimed at simulation-based building environment and HVAC design. Functions on energy and environmental evaluation are almost the same for these four programs, but each with peculiar algorithms due to their design concept. HVACSIM^{+}(J) is a Japanese version of original public domain program HVACSIM^{+} that had been developed in NBS (presently, NIST) in 1985. It is a typical HVAC dynamic simulation program and it cannot be directly compared with other four programs. Appendix-1 shows comparison of typical simulation elements starting from weather data to HVAC system components and controls. In the last line actual system that will be explained in the next section is compared with others.

2.2 Reference building and HVAC system

The reference building and its HVAC system was composed based on existing building plan. The typical VAV system was adopted as model floor plan and model HVAC system and it was multiplied with ten to form 3, 300-m2 building. The floor plan is shown in Fig.1. The diagram of HVAC system is shown in Fig.2. Actual installation has two AHUs, each assigned to the east and west zones, each of which includes interior and perimeter zones. This assignment may not be good enough for environmental control of whole room, but in this study AHU of the reference system was assigned to the interior zone and the perimeter zone according to the original design.

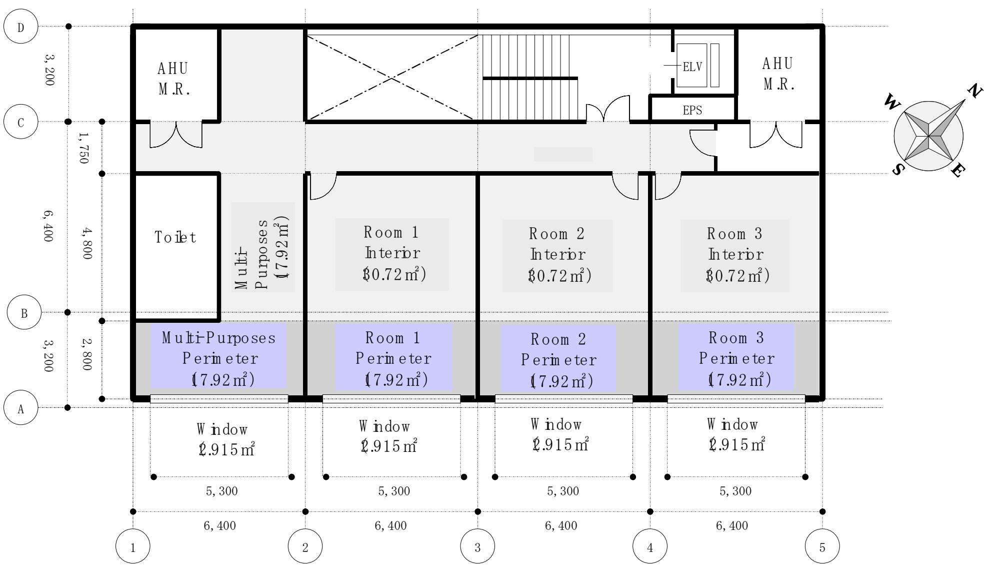


Figure 1. Reference floor plan for comparative study

The specifications of main equipments of the reference system are shown in Table 1. The common calculation conditions are described in Table 2. Differentiated conditions due to difference of program characteristics and trivial lack of adjustment are also described in the last column of Appendix-2. Hourly heating and cooling peak load as design values were calculated by Micro Peak, a dedicated Japanese program for calculating peak load based on TAC/2.5% weather data.

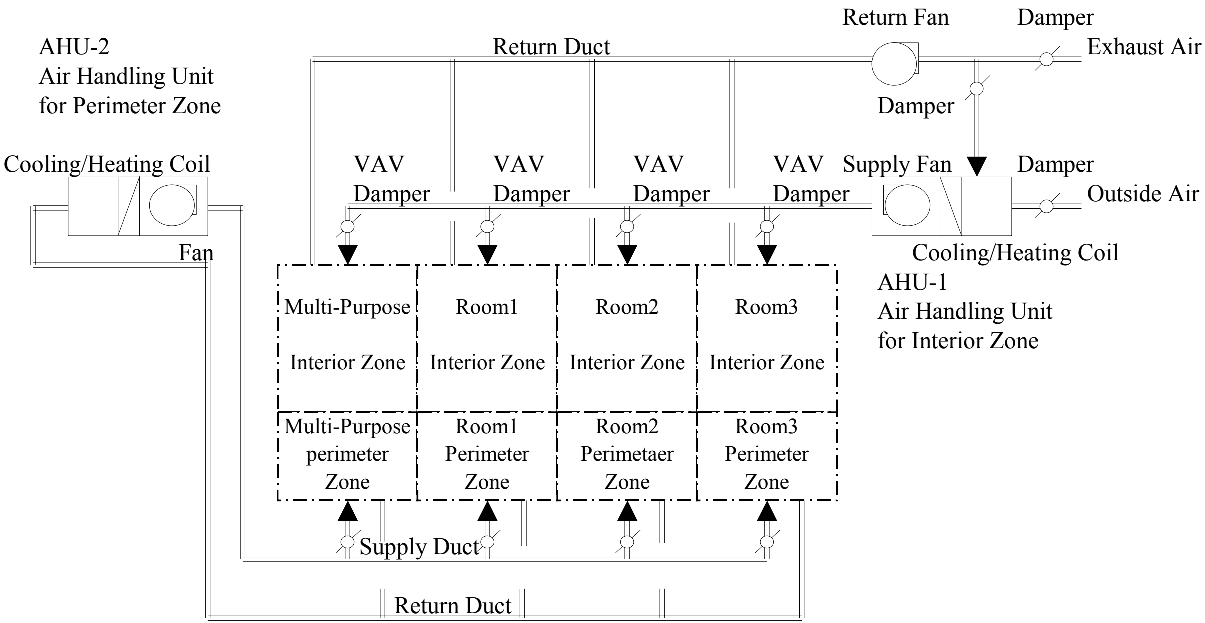


Figure 2. Reference system diagram for comparative study

Table 1. Specifications of main euipments of reference system

Air Handling unit (for Interior-zone) ×10		
Cooling Capacity		32kW
Supply Fan		6000m3/h×879Pa
Return fan		6000m3/h×361Pa
Coil		0.6㎡ 6 raws 65 l/min
Water Temperature	7/14℃ (cooling)	47/40℃ (heating)
Air Handling unit (for Perimeter-zone)×10		
Cooling Capacity		27kW
Supply Fan		5700m3/h×879Pa
Water Temperature	7/12℃ (cooling)	47/42℃ (heating)
Heat pump Chiller×2		
Cooling Capacity		100 kW
Heating Capacity		118 kW
Water Flowrate		200 l/min
Thermal Storage Tank	Multi-connected complete mixing type	
	RC Water Tank 16m3×20tanks	

Table 2. Common conditions for comparative study

. June to September for cooling, November to March for heating
. Operation time of air conditioning equipments: 8:00-19:00
. OA cut for preheating: 8:00-9:00
. OA intake: 600m3/h/floor
. Room Set Point: summer DB26℃RH50% winterDB22℃RH40%
. Zoning: interior zone/perimeter zone
. Lower limit of VAV air flow rate: 50% of minimum
. Heat Source System: Thermal storage system using AHP(Air-soure HeatPumps)
. Performance characteristics of fan, pump, heat pump are defined as manufacturer's
. Internal heat gain schedules are set based on measurement
. Weather Data: original format of SHASE's standard year weather data(TOKYO) or converted format to TRY, TMY, TMY2,WYEC, and so on.

2.3 Comparison of calculation results

Heat Extraction Rate

Fig.3 shows hourly HER (Heat Extraction Rate) of coil on peak day for cooling and heating, and Fig.4 shows monthly HER. Fig.6 shows maximum HER and annual HER calculated using each program compared with actual operation values and design values.

As is shown in fig.6 and Appendix-2, the maximum HER is rather dispersed; 428 to 556 kW (actual value: 503 kW) in summer and 212 to 554 kW (actual value: 319 kW) in winter except HVACSIM+. It is estimated that such dispersion is caused by methods of the mixed calculation between the interior and the perimeter at night and dispersion in the wall configuration and glass material physical values prepared in the programs. The calculated values are different from the actual value because the heat gain pattern in the rooms is different on every day naturally, and because the heat gains is different from the value at the time of design. In addition, the room environment is “26°C in summer, 22°C in winter” in the design condition, but is “about 25°C” during both cooling and heating operations.

In comparison of the annual Heat Extraction Ratio, which is shown in Fig.6 and Appendix-2, dispersion is detected also; over 175 to 208 MWh (actual value: 180 MWh) in the cooling load and 11 to 38 MWh (actual value: 78 MWh) in the heating load. There is the tendency that the cooling load is overestimated, and the heating load is underestimated. Handling of the internal heat generation should be considered here also. In addition, the operating hours are “from 8:00 to 18:00” in the design condition, but the air-conditioning system is actually operated for almost 14 hours on many days. And in the actual operation, outside air is not cut during preheating. In addition, actually introduced outside air is different from calculated value without doubt

Energy consumption

Fig.5 shows monthly electric power consumption of fans, pumps and heat pumps. Fig.7 shows annual consumption compared with actual consumption, which shows considerable dispersion. It was reasoned that differences of available air-conditioning/ventilation systems, heat source system/equipments and control strategy among each program were one of the causes of dispersion. The trial to cope with the reference system in the restricted condition leads to dispersion. In addition, the dispersion is partially caused by the difference in the equipment model (characteristics) among programs though we have made as much efforts as possible to achieve alignment. As each program was developed for not quite the same purposes, and each program reflects technical background in each country as well, the designer must examine sufficiently the desired output and the compatibility between the target system and the program, and then adopt the suitable program.

3. Case studies on postulated application to commissioning using each program

Henceforth postulated application to commissioning is discussed, examining the basic design requirements for the reference system using existing simulation tools. The outline of applied cases is described below.

3.1 Preset of room temperature set point and minimum openings of the VAV

The effect of the preset of room temperature set point and minimum opening ratio of the VAV on the energy consumption is examined using HASP/ACSS and EnergyPlus. Fig.8 and Table 3 show the results using HASP/ACSS. Fig.9 and Table 4 show results of the effect on a peak day (8/17) in summer using EnergyPlus. As shown in fig 8.1 the energy consumption for cooling and heating is reduced by mitigation of the set point temperature (Cooling: 24-26-28°C, Heating: 24-22-20°C). Fig.8.2 shows that the energy consumption declines by about 20 % by changing the minimum openings ratio of VAV from 60 % to 40 %. In Fig.8.2, the difference in the annual power consumption between the reset case and the constant case of supply air temperature is mainly generated in the heat source equipment. With regard to the total value, the electric power consumption is larger by about 5% in case for the constant supply air temperature control for each option of minimum opening. In Fig.9, changing minimum openings ratio from 30 % to 50 %, it is shown that room temperature becomes below the set point on the off peak day (6/27).

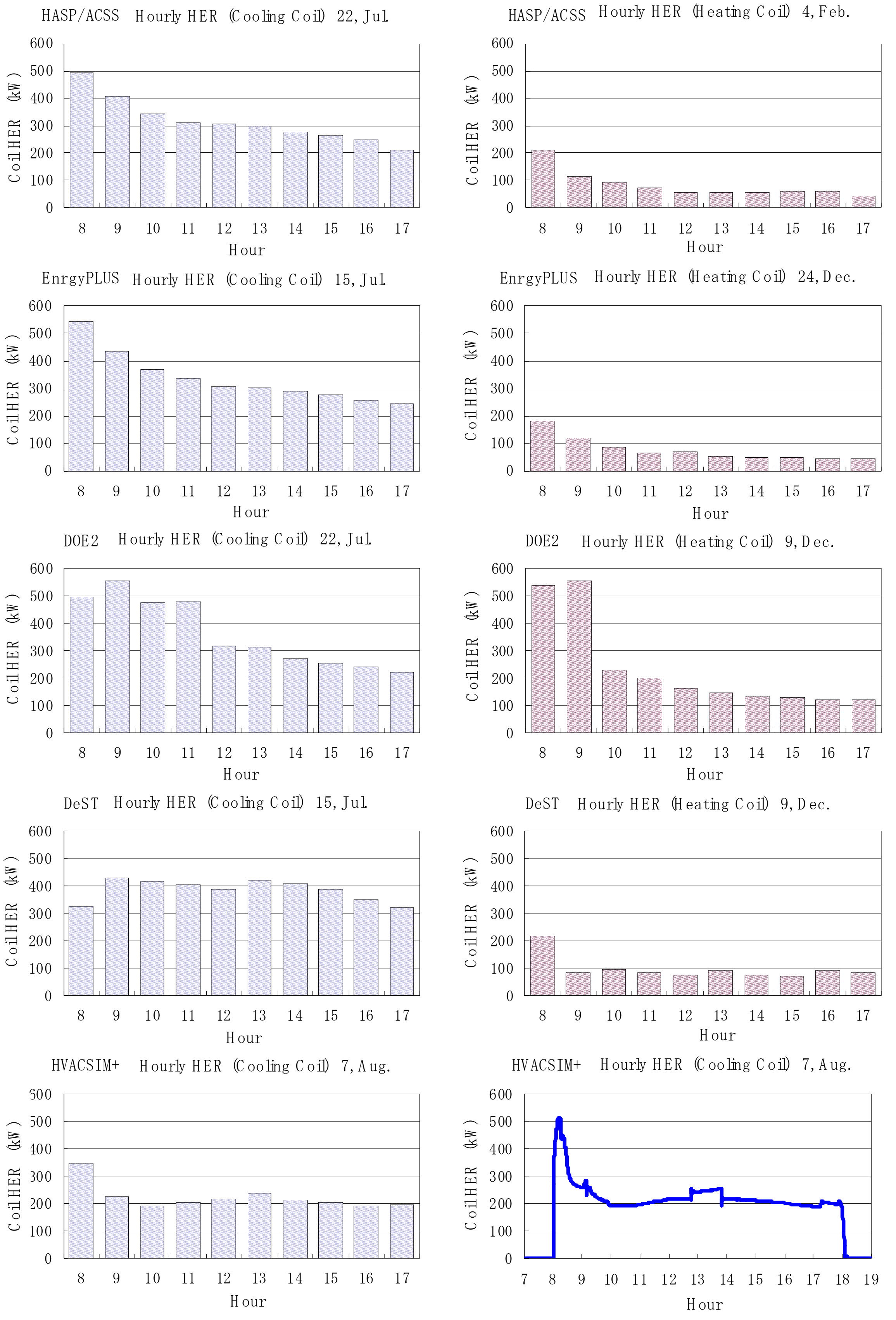


Figure 3. Hourly Heat Extraction Rate of coil on peak day for cooling and heating

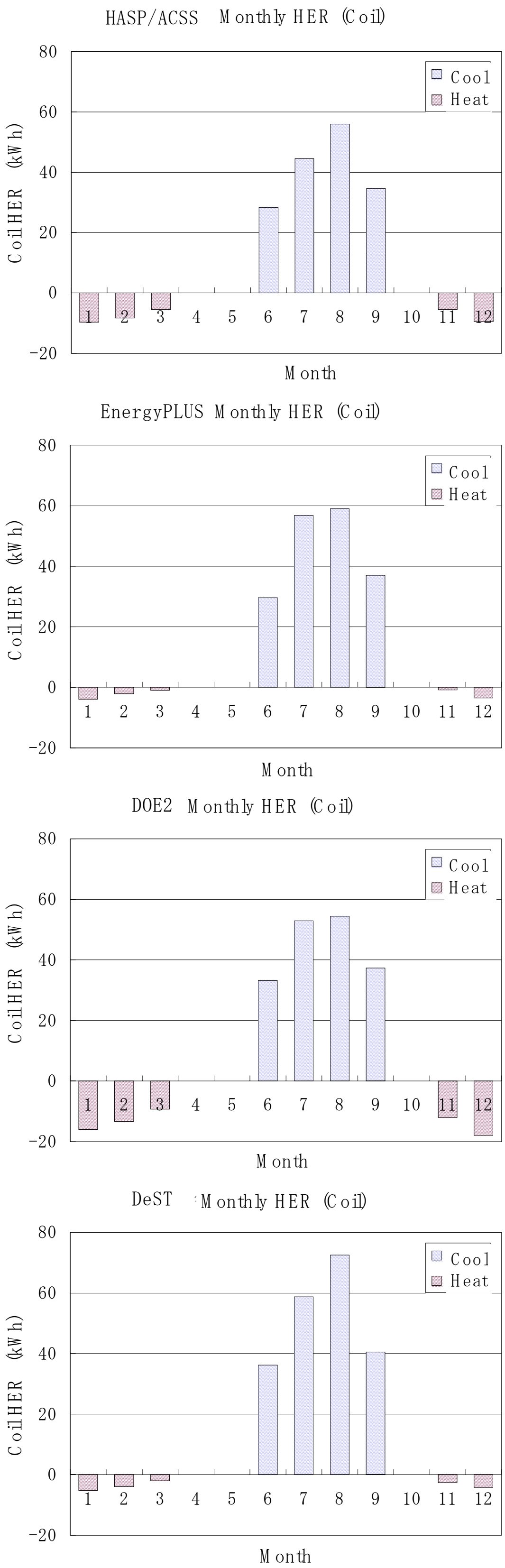


Figure 4. Monthly Heat Extraction Rate of coolimg and heating coil

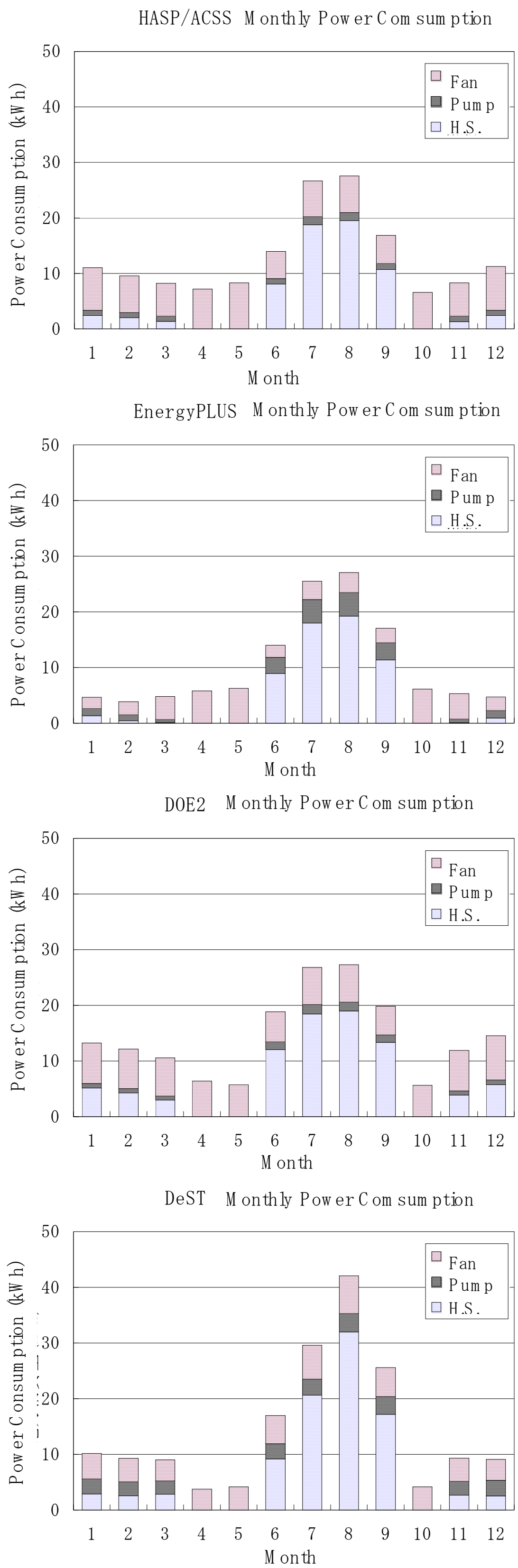


Figure 5. Monthly electric power consumption of fans, pumps and heat pumps

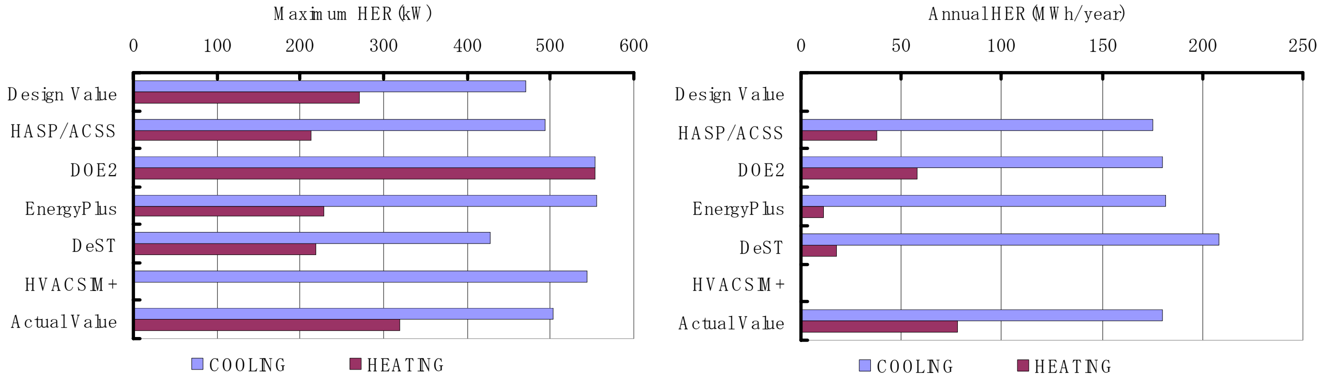


Figure 6. Comparison of coil HER(Heat Extraction Rate)

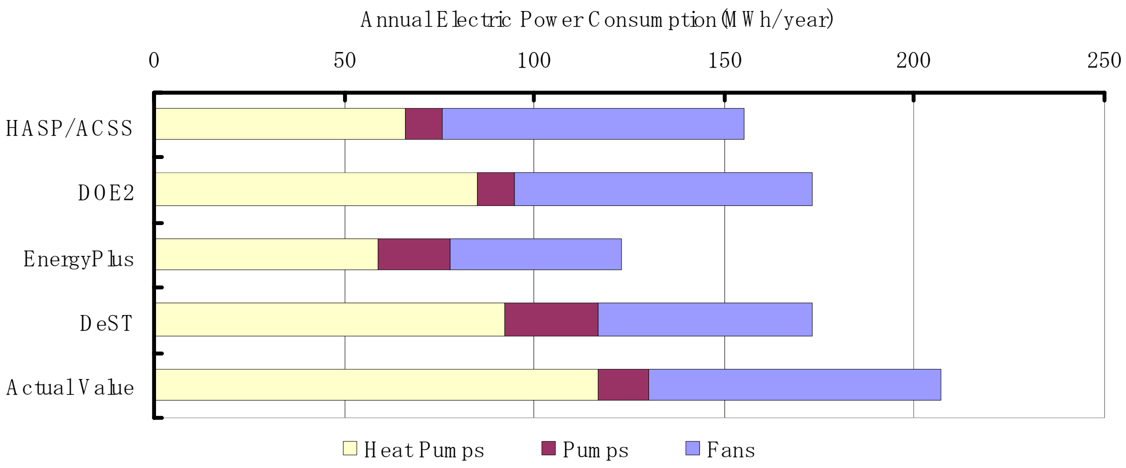


Figure 7. Comparison of electric power consumption

3.2 Supply air temperature control method using the outside air temperature

Table 6 and Fig.10 show the calculation results on the effect when the supply air temperature is reset due schedule to the outside air temperature, as shown in Fig.11, using DOE-2. As is shown in Table 6 the coil HER on peak day is reduced considerably especially in winter for reset case. The supply air temperature setting in winter is an important factor in energy saving. In Reset case in which the supply air temperature in winter is fixed at 20°C, the cooling/heating (reheating) load in winter is reduced compared with the case in which the supply air temperature is fixed at 16°C. When the supply air temperature is set to 20°C, however, the difference of supply and return air temperature becomes smaller and the fan power increases.

3.3 Effect of VAV parameters

As is shown in Table 7, the room environment and energy consumption using HVACSIM+ while changing the VAV control parameters are examined. In Fig.12 behaviors of the VAV damper and room temperature on a peak day in summer is shown. As is shown in Fig. 12, the coil HER and power consumption are minimum in “Case-02”, which is realized by the effect of the “offset”.

3.4 Effect of reduction of the heat source equipment performance

The effect of reduction of the air-source heat pump chiller performance on the system using HVACSIM+ is examined. A case in which the efficiency of the evaporator is reduced (that is, the heat exchange efficiency is reduced by 50%) due to increase of scaling factor, etc. is postulated. Figure 13 shows the examination result. The evaporation temperature decreases considerably. The evaporator efficiency is reduced, the flow rate increases on the bypass side (low temperature bath side) of the three-way valve at the entrance of the chiller, and the difference between inlet and outlet temperature of the chilled water. These results give effect on the temperature profile of the thermal storage tank also. It is seen also that the COP is reduced.

3.5 Temperature difference using the coil design

Using DOE-2, the energy performance is calculated for cases in which the design temperature difference of the coils is 7°C and 5°C. Because the reference system adopts the VWV controls as the secondary circulation system, the pump power increases by about 15% when the design temperature difference is changed from 7°C to 5°C.

3.6 Intake of outside air

Using DeST, a case in which the outside air quantity is always constant (600 CMH) and a case in which the outside air quantity is controlled according to the number of people inside the room are compared. As a result, the heating peak load is reduced by about 9%, and the total annual heating load is reduced by about 12%.

Table 3. Conditons of case study using HASP / ACSS

Room Temperature Set Point

Case	Cooling	Heating
24-24	24℃	24℃
26-22	26℃	22℃
28-20	28℃	20℃

VAV Minimum Opening Ratio

Case	Cooling	Heating
MIN60	60%	60%
MIN50	50%	50%
MIN40	40%	40%

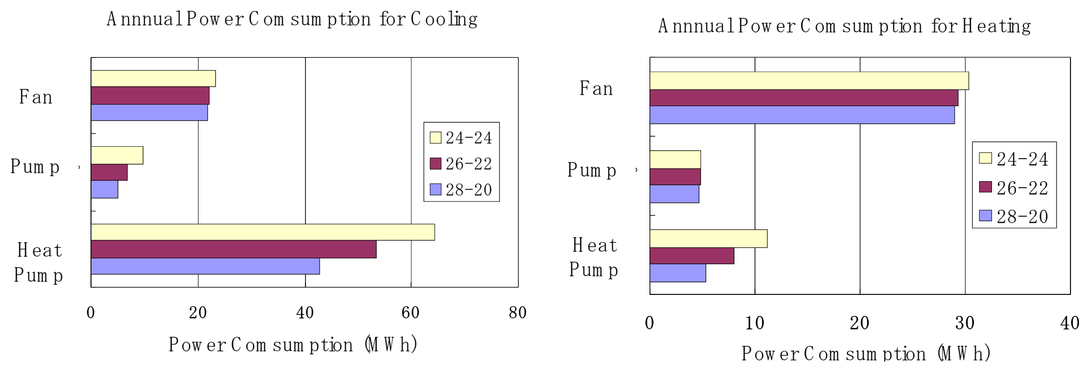
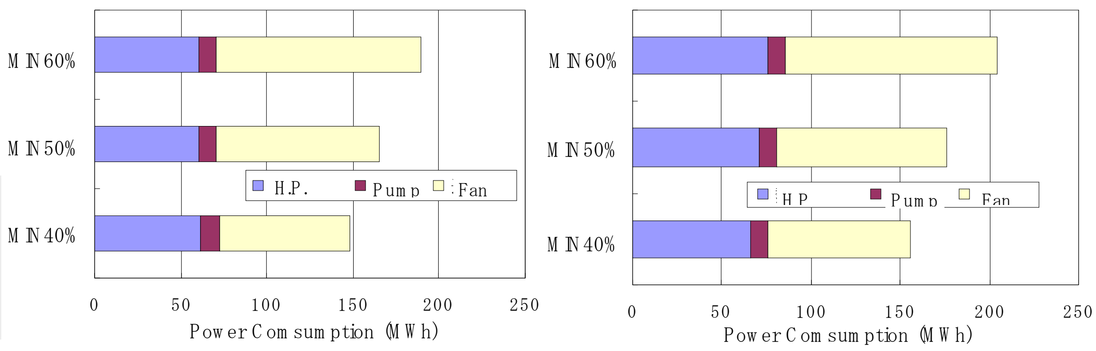


Figure 8.1 Influence on annnual power consumption of set point temperature



(a)Reset Contorol of Supply Air Temperature

(b)Constant Supply Air Temperature

Figure 8.2 Influence on annnual power consumption of VAV minimum opening Ratio

Figure 8. Results of case study using HASP/ACSS

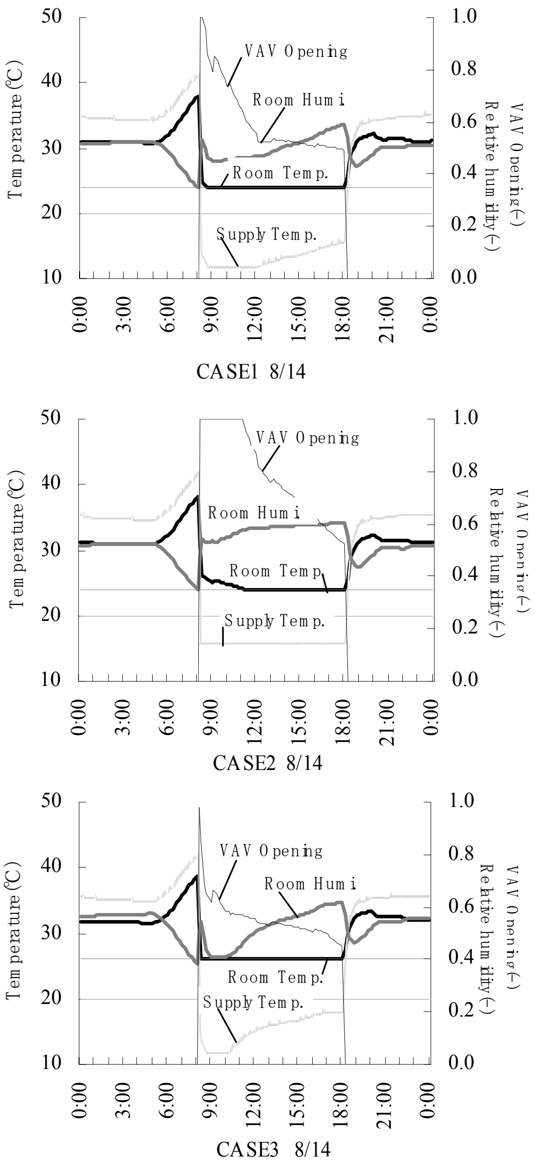


Table 4. Conditions of simulation cases

	Supply Air Temperature	VAV MIN. Opening	Room Temp. Set Point
CASE 1	12～18℃	0.3	24℃
CASE 2	16℃	0.3	24℃
CASE 3	12～18℃	0.3	26℃
CASE 4	12～18℃	0.5	24℃

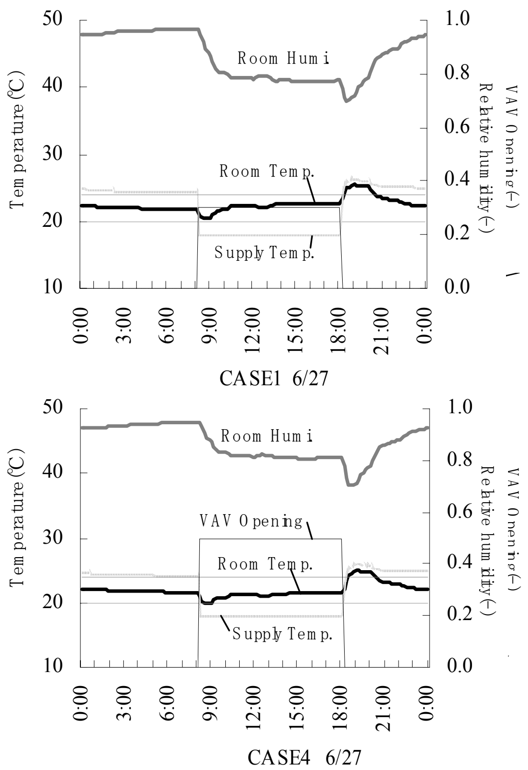


Figure 9. Results of case study using EnergyPlus

Table 5. Results of case study using EnergyPlus

	Coil HER				Electric Power Consumption			
	Peak Day [MJ/day]		Annual [GJ/year]		Peak Day [MJ/Day]	Annual [GJ/year]	Per Floor Area [MJ/m²･year]	
	Cooling (8/14)	Heating (1/21)	Cooling	Heating			Secondary	Primary
CASE 1	1,187.4	55.6	60.5	0.6	869.3	138.9	565.1	1,610.1
CASE 2	1,151.0	55.6	60.5	0.6	868.1	138.4	563.2	1,604.7
CASE 3	1,074.5	55.6	52.1	0.6	813.0	134.7	548.2	1,562.1
CASE 4	1,187.2	48.9	61.5	0.5	869.3	139.0	565.6	1,611.7

Table 6. Results of case study using DOE-2

Supply-Air Temperature		Heat Extraction Rate (COIL)			Annual Power Consumption		
		Annnual (MWh/year)	Daily (Peak Day) (kWh/day)	Maximum (kW)	Fan (MWh/year)	Pump (MWh/year)	Heat Source (MWh/year)
Fix(16°C)	Cooling	299	2871	420	51	19	103
	Heating	31	820	284			39
Reset-①	Cooling	274	2842	420	62	17	96
	Heating	14	322	269			19
Reset-②	Cooling	295	2842	420	52	19	102
	Heating	28	615	284			36

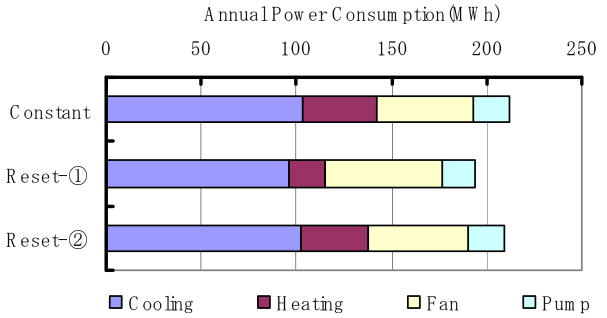


Figure 10. Influence on annnual power consumption of supply air temperature reset schedule

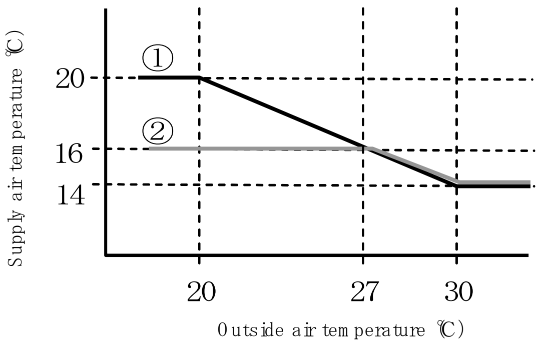


Figure 11. Supply air temperature reset schedules

4. Conclusion

This report has summarized the necessity of simulation tools in commissioning at first, and then outlined the features of and restrictions in the existing HVAC system simulation programs. Next, the reference system was set and calculation results using five typical existing simulation programs were compared. At the end, application to commissioning which is the original purpose of this report was examined. Setting indexes, such as energy consumption and indoor environment, room temperature set point, VAV minimum opening, supply air temperature reset schedules, design temperature difference of the coils, VAV control parameters, were examined. Though the design phase was postulated here, application seems possible also to the operation phase. In conclusion, though several problems remain still unsolved, authors believe that this research will contribute to open the window for effective utilization of public-available simulation programs for design as well as commissioning of HVAC system at various phases.

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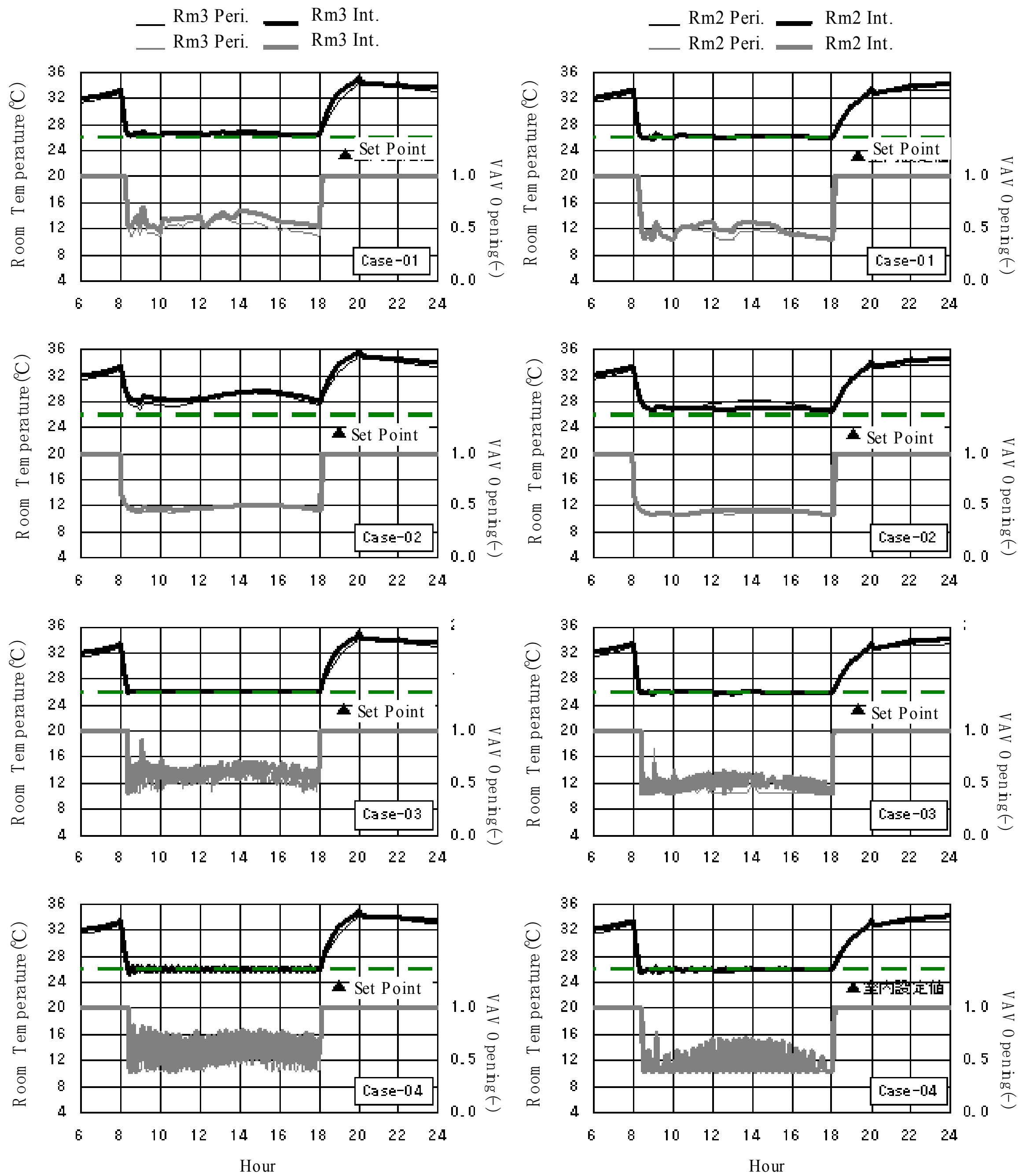

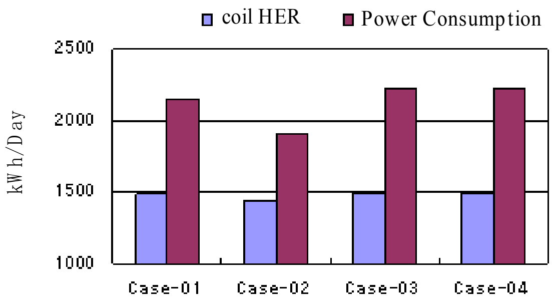

Coil HER and Power Consumption

Table 7 PI Parameters of VAV controller

	Control	Kp	Ki
Case-01	P	0.5	0
Case-02	P	0.05	0
Case-03	P	10	0
Case-04	PI	0.5	0.05

Figure 12. Results of PID parameter study using HVACSIM+

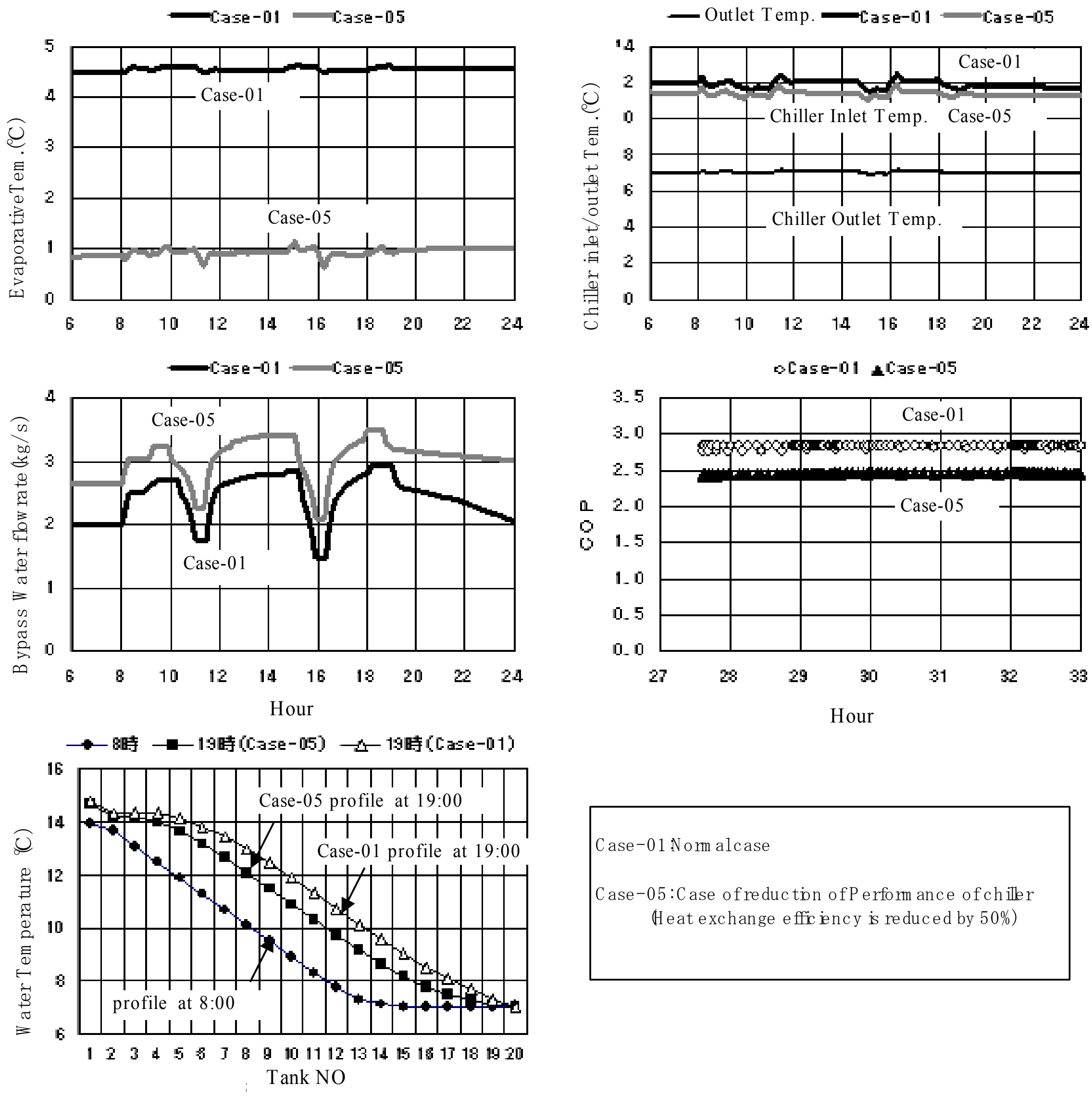

Figure 13. Results of dynamic simulationin case of reduction chiller performance using HVACSIM+

Appendix-1 Comparison of simulation functions among five typical programs

Program name	static / dynamic	weather data cakender	heat transfer calculation through opaque wall	energy mixing calculation between zones	selecting / structuring HVAC system	method of characteristics input of refrigeration machine / HP
ACSS	･static	･HASP format w/calendar ･holiday setting available	･response factor method (one hour calculation step)	･100% mixing during non-operation hours at night	･select from menu	･select from default characteristics or input characteristic values by quadratic approximation
EnergyPlus	･static + dynamic (future)	･TMY2 format, basically, then converted to E/E(.epw) format w/calendar ･holiday setting available	･CTF method with solution by state space equations (variable time calculation step)	･available but with fixed value (not to use here	･select from menu (present) and/ or module type (future) (structured by modules)	･input regression coefficients
DOE2	･static	･FMT(.fmt) binary format and can be converted from various formats (TMY,TMY2,CTMY,WYEC,CTZ,TRY) ･US calendar and holiday setting available	･CTF(conduction transfer function) method (one hour calculation step)	･unavailable	･select from menu	･select from default characteristics or input characteristic values by quadratic approximation
DeST	･static	･TRY format	･direct solution by state space equations (one hour calculation step)	･available based on inputted vetilations per hour (both for operation hours and non-operation hours)	･select from menu	･select from default characteristics or input characteristic values by quadratic approximation
HVACSIM+(J)	･dynamic	･converted from HASP format w/calendar ･calendar can be input	･CTF method (ten min. calculation time step)	･available with a mixing model (both for operation and non-operation hour, and both for adjacent I/P and I/I zones)	･module method (arbitrarily structured)	･define in the program sourse for specific equipments
Actual System	—	—	—	—	—	—

Program name	characteristis input of fan / piump	VAV controls	outside air intake controls	heat transfer calculation of air to water cooling / heating coils	thermal storage system	notes
ACSS	･select defaul characteristics ･input characteristic vakues by quadratic approximation ･default for control characteristics	･select a control type among two (min. air volume compensatio, max. air volume compensation or fixed) ･OA intake volume is constant even at VAV	･min. OA intake cut ･OA cooling (economizer) ･total hear exchanger (heat wheel)	･dry part and wet part of the coil is seperated in calsulation, as well as equivalent simple wet coil model ･min water flow set at 10% by default, ･heat transfer coefficient is either set constant with input air and water velocity or recalculated at	･water thermal storage system (multi-connected complete mixing tanks)	
EnergyPlus	･input regression coefficients (w/samples) ･default for control characteristics	･limited only to terminal reheat ･fixed at min. air volume at reheat mode operation ･air volume mode at VAV is selected among proportional to VAV, fixed and scheduled	･OA intake schedule control ･OA cooling (economizer) ･total hear exchanger (heat wheel)	･same as the model for HVACSIM+ but fixed as plate-fin coil	･none (except for Trombe wall)	･warm air supply is not applicable in case of VAV ･central type air-sourse heat pump is not included ･with or without VAV terminal reheating in cooling and all energy consumed at reheaters are summed up as the heating energy
DOE2	･select defaul characteristics ･control caracteristics: input regressive coefficient for pumps, select default type for fans	･limited only to terminal reheat ･fixed at min. air volume at reheat mode operation ･OA intake volume is constant even at VAV	･OA intake schedule control ･OA cooling (economizer) ･total hear exchanger (heat wheel)	･bypass factor method ･input bypass factor and rated cooling capacity and calculate air delivery state to suffice cooling capacity, inlet air state and air flow rate	･water thermal storage system (single complete mixing tank)	･intermediate season without air-conditioning is difficult to set up (can be estimated by deducting energy consumed in these months) ･central type air-sourse heat pump is not included ･VAV terminal reheat at cooling is always applied and all energy consumed at reheaters are summed up
DeST	･select defaul characteristics ･input regressive coefficient ･default for control characteristics	･searchig control for min. energy point (space atate method) ･air volume mode at VAV is selected either fixed or variable	･min. OA intake cut ･occupancy demand control	･select equation to calculate eitrher dry or wet raw of the coil judging from inlet air state ･for VAV air side surface heat transfer rate, fin efficiency, is recalculated ･equivalent simple wet coil model	･water thermal storage tank (multi-connected incomplete mixing tanks)	･fixed amount of air infiltration is summed up in the outside air load ･weather data does not include cloud amount and wind velocity ･night radiation is not included
HVACSIM+(J)	･input regressive coefficients ･select types for control characteristics (develop)	･controllable in arbitrary mode by design ･OA intake volume is variable at VAV	･defined by the user combining dampers and controllers	･border of dry and wet raw of the coil is determined as the result of heat transfer based on total heat calculation ･coefficients of heat transfer for both air and water sides are calculated in detail ･either plate-fin or round-fin can be selected	･various types of thermal storage system due to definition (multi-connected complete mixing tanks/ temperature staratified tanks)	
Actual System	･(pump) pressure differece between headers set constant for bypass water flow control	･load reset mode (Yamatake method)	･OA cooling (economizer) ･CO2 demand control	—	multi-connected complete mixing water thermal storage tanks	—

Appendix-2 Comparison of simulation results among five typi

program names		hourly peak perimeter	hourly peak interior	hourly peak total	yearly HER perimeter	yearly HER interior	yearly HER total	yearly power consumption (based on secondary and primary) fan	pump	heat pump	total	Primary COP	NOTES conditions for simulations
MicroPeak (Peak cooling and heating load)	cooling	210 kW (64 W/㎡)	260 kW (79 W/㎡)	**470** kW (142 W/㎡)									
	heating	130 kW (39 W/㎡)	140 kW (42 W/㎡)	**270** kW (82 W/㎡)									
HASP/ACSS	cooling	226 kW (68 W/㎡)	267 kW (81 W/㎡)	**493** kW (149 W/㎡)	74 MWh/a (266 GJ/a) (81 MJ/a/㎡)	101 MWh/a (364 GJ/a) (110 MJ/a/㎡)	**175** MWh/a (630 GJ/a) (191 MJ/a/㎡)	79 MWh/a	10 MWh/a	66 MWh/a	(secondaru energy total **155** MWh/a (primary energy total) 1,589 GJ/a (per total floor area) 482 MJ/a/㎡	0.48	・VAV supply temperature is fixed at 16℃ for coolimg and at 25℃ for heating ・OA intake volume is set constant in spite of VAV
	heating	103 kW (31 W/㎡)	109 kW (33 W/㎡)	**212** kW (64 W/㎡)	7 MWh/a (25 GJ/a) (8 MJ/a/㎡)	31 MWh/a (112 GJ/a) (34 MJ/a/㎡)	**38** MWh/a (137 GJ/a) (41 MJ/a/㎡)						
DOE2	cooling	243 kW (74 W/㎡)	310 kW (94 W/㎡)	**553** kW (168 W/㎡)	98 MWh/a (353 GJ/a) (107 MJ/a/㎡)	82 MWh/a (295 GJ/a) (89 MJ/a/㎡)	**180** MWh/a (648 GJ/a) (196 MJ/a/㎡)	78 MWh/a	10 MWh/a	85 MWh/a	(secondaru energy total **173** MWh/a (primary energy total) 1,774 GJ/a (per total floor area) 538 MJ/a/㎡	0.48	・OA intake volume is set constant in spite of VAV ・Heating coil installed in VAV terminal and operated through the year ・Heat sourse system: dedicated chiller for cooling, electric boiler for haracteristic of which was set the same as that of given AHP. ・Energy consumption in April, May and October was deducted except
	heating	254 kW (77 W/㎡)	300 kW (91 W/㎡)	**554** kW (168 W/㎡)	26 MWh/a (94 GJ/a) (28 MJ/a/㎡)	32 MWh/a (115 GJ/a) (35 MJ/a/㎡)	**58** MWh/a (209 GJ/a) (63 MJ/a/㎡)						
EnergyPlus	cooling	321 kW (97 W/㎡)	235 kW (71 W/㎡)	**556** kW (168 W/㎡)	81 MWh/a (290 GJ/a) (88 MJ/a/㎡)	102 MWh/a (366 GJ/a) (111 MJ/a/㎡)	**182** MWh/a (657 GJ/a) (199 MJ/a/㎡)	46 MWh/a	19 MWh/a	59 MWh/a	(secondaru energy total **123** MWh/a (primary energy total) 1,266 GJ/a (per total floor area) 384 MJ/a/㎡	0.55	・VAV supply temperature is set at 16℃ ・OA intake volume is set constant in spite of VAV ・Heating coil installed in VAV terminal and operated only in winter ・Heat sourse system: dedicated chiller for cooling, electric boiler for heating characteristic of which was set the same as that of given AHP.
	heating	121 kW (37 W/㎡)	108 kW (33 W/㎡)	**229** kW (69 W/㎡)	6 MWh/a (21 GJ/a) (6 MJ/a/㎡)	5 MWh/a (19 GJ/a) (6 MJ/a/㎡)	**11** MWh/a (41 GJ/a) (12 MJ/a/㎡)						
DeST	cooling			**428** kW (130 W/㎡)			**208** MWh/a (749 GJ/a) (227 MJ/a/㎡)	56 MWh/a	25 MWh/a	93 MWh/a	(secondaru energy total **174** MWh/a (primary energy total) 1,779 GJ/a (per total floor area) 539 MJ/a/㎡	0.46	・VAV supply air temperature set above 16C in summer and between 14C and 32C in winter. VAV supply air temperature reset is searched for by predicted min. energy strategy ・OA intake volume is set constant in spite of VAV ・Weather data does not include cloud amount and wind velocity, which affects loads caused by infiltration and night radiation load.
	heating			**218** kW (66 W/㎡)			**18** MWh/a (65 GJ/a) 19.64 MJ/a/㎡)						
Corrected actual results (year 2002 measured for the 3rd flloor, multiplied by ten)	cooling			**503** kW (152 W/㎡)			**180** MWh/a (648 GJ/a) (196 MJ/a/㎡)	77 MWh/a	13 MWh/a	117 MWh/a	(secondaru energy total **207** MWh/a (primary energy total) 2,123 GJ/a (per total floor area) 643 MJ/a/㎡	0.44	・Energy consumpton in April, May and October was deducted from the yearly total data except for han energy. ・Energy consumpton between 18 hrs and 8 hrs was deducted from dayly total data. ・Lower limit of VAV air flow rate is 30% ・OA introduction was adjusted as 360m3/h(720m3/h/floor) at the VAV min. air flow rate for each AHU. therefore, OA introduction increases at the higher VAV air flow rate. (The standard rate is 300 m3/hr for each AHU at the max. air flow rate) ・Power for chiller and pumps are proportionally divided for the third and multiplied by ten to meet the simulation ncondition.
	heating			**319** kW (97 W/㎡)			**78** MWh/a (281 GJ/a) 85.09 MJ/a/㎡)						

NOTES AHU: Air Handling Unit HER: Heat Extraction Rate OA: Outside Air VAV: Variable Air Volume VWV: Variable Water Volume ASP: Air Sourse Heat Pu